

Final Technical Report

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N-46-CR
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Project Title: Studies of the Intrinsic Complexities of Magnetotail Ion
Distributions: Theory and Observations

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Period of Award: 5/01/96 – 4/30/98

Grant Number: NAGW-4553

Summary

This year we have studied the relationship between the structure seen in measured distribution functions and the detailed magnetospheric configuration. Results from our recent studies using time-dependent large-scale kinetic (LSK) calculations are used to infer the sources of the ions in the velocity distribution functions measured by a single spacecraft (Geotail). Our results strongly indicate that the different ion sources and acceleration mechanisms producing a measured distribution function can explain this structure. Moreover, individual structures within distribution functions were traced back to single sources. We also confirmed the fractal nature of ion distributions.

A. Ion Sources and Acceleration Mechanisms Leading to Observed Distribution Functions

Distribution functions observed by the Geotail spacecraft on May 23, 1995 at $x = 10 R_E$ downtail, and on February 9, 1995, at $x = 30 R_E$ downtail, attracted our attention because they had an abundance of small scale structures. These distribution functions were used in a time-dependent large scale kinetic model to investigate the sources and the acceleration mechanisms of the particles. Time dependent magnetic and electric fields were obtained from global magnetohydrodynamic (MHD) simulations of the magnetosphere driven by solar wind input indicated by Wind spacecraft measurements. These measurements provided the solar wind density, magnetic field, pressure, and velocity for the interval preceding the measurement of the local distribution functions. Ions were initially distributed at the location of Geotail according to

the phase space densities measured by Geotail. They were followed backward in time through the MHD simulations' fields, which were also regressed in time, until they reached a magnetospheric boundary (magnetopause or ionosphere). A brief summary of the results of our calculations follows.

A.1 May 23, 1995 Event

1. Three sources of the high latitude ionosphere, the plasma mantle (with both a distant tail and a near-Earth tail segment, and the low latitude boundary layer (LLBL), contributed significantly to the equatorial ion population.
2. Most ionospheric particles were adiabatic and reached Geotail directly along field lines without mirror bouncing.
3. Low latitude boundary layer ions reached the Geotail location by convecting earthward from the dawnward flank of the magnetosphere adiabatic motion dominating. They primarily occupied the low energy part of the distribution.
4. Investigation of mantle ion trajectories indicate that they originated from two distinct populations. The first population consisted of adiabatic ions from the near-Earth plasma mantle, and the other population originated from the distant mantle. These ions had interacted strongly with the thin current sheet tailward of Geotail and experienced nonadiabatic ($k < 1$) acceleration and substantial energization. The second ion population supplied the bulk of the higher energy ions in the distribution.
5. There was a one-to-one correspondence between each of the structures in the low energy part of the Geotail distribution and a specific particle source.
6. Different source regions and acceleration mechanisms acting in the tail are responsible for the structure in the distribution function.
7. The structures at high energies result mainly from nonadiabatic behavior.

A.2 February 9, 1995 Event

Despite the quiet solar wind conditions observed on February 9, 1995, there were significant changes in distribution functions at Geotail between 1300 UT and 1400 UT. We modeled these changes with the MHD/LSK model as described above, with the following results.

1. At 1310 UT, all of the ions measured by Geotail originated from the duskside LLBL, from a narrow strip (in y and z) along the magnetopause. Because the magnetotail was twisted by the IMF B_y component, the current sheet is increasingly tilted out of the $z = 0$ plane at locations further down the tail. Therefore, while the location of the duskside LLBL source was close to the equatorial plane near the Earth, it increased steadily in z downtail. The particles followed guiding center orbits and were adiabatic. Counter-streaming ions seen in the distribution were due to mirror bouncing in the region around midnight, earthward of Geotail.
2. At 1325 UT, Geotail was entering a region of closed field lines. At that time ions from the dawnside LLBL gained access to the vicinity of Geotail. The LLBL ions had originated from broad regions in z centered on the equatorial plane. Most of them at this point experienced nonadiabatic acceleration. The duskside magnetopause remained the dominant source of ions during this time period. Unlike the previous time interval, ionospheric particles had contributed only a small fraction (1 %) of the particles measured by Geotail.
3. At 1347 UT, Geotail was embedded in closed field lines. During this time interval the dawnside replaced the duskside LLBL as the dominant source of ions. The particles' behavior during this interval was characterized by multiple nonadiabatic current sheet crossings prior to their dawnward drift to Geotail.
4. Time dependent MHD/LSK calculations were found to be helpful in explaining the physical processes leading to observed distribution functions.

B. Fractal Dimension of Magnetotail Distribution Functions

Methods have been developed to measure the fractal dimension D of distribution functions measured by spacecraft and produced using LSK calculations. D reflects the amount of structure in the distribution functions. A value of D near 1.5 indicates a distribution function with a great deal of fine structure, $D = 1$ corresponds to a distribution function such as a bi-Maxwellian with smooth, closed isodensity contours. The LSK calculation showed that D was near 1.5 in the plasma sheet boundary layer, and it decreased slowly in the outer central sheet and then to near 1 in the central plasma sheet, because of multiple current sheet crossings. Distribution functions measured by Galileo and Geotail also reflected this type of pattern.

C. Future Work on Continuation Grant NAG5-4683

During the next year, the process of identifying the source and acceleration mechanisms in the geomagnetic tail will continue, but this year will employ the distribution functions from two additional spacecraft (Geotail, Interball). We will also begin studying the transport of high energy ($E > 100$ keV) oxygen ions observed by Geotail and will investigate the relative importance of the different ion populations (of solar wind and ionospheric origin) in the plasma sheet during substorms.

D. Administrative Matters

Due to NASA reorganization, the third year funding of this research was processed through Goddard Space Flight Center under the new grant NAG5-4683.

D. Patents or Inventions

None

Publications

1. Ashour-Abdalla, M., L. M. Zelenyi, V. Perroomian, L. A. Frank, and W. R. Paterson, Coarse grained texture of ion distributions in the magnetotail: A fractal-like approach, *J. Geophys. Res.*, 101, 15,287, 1996.
2. Ashour-Abdalla, M. M. El-Alaoui, V. Perroomian, J. Raeder, R. J. Walker, R. L. Richard, L. M. Zelenyi, L. A. Frank, W. R. Paterson, J. M. Bosqued, R. P. Lepping, K. Ogilvie, S. Kokubun, and T. Yamamoto, Ion sources and acceleration mechanisms inferred from local distribution functions, *Geophys. Res. Lett.*, accepted 1997.
3. Ashour-Abdalla, M., L. M. Zelenyi, J. Berchem, M. El-Alaoui, V. Perroomian, J. Raeder, R. L. Richard, D. Schriver, R. J. Walker, L. A. Frank, W. R. Paterson, K. Ackerson, S. Kokubun, T. Yamamoto, R. P. Lepping, and K. Ogilvie, Inferring particle sources for observed distribution function, *Proceedings of the 1996 Huntsville Workshop on "Encounter between Global Observations and Models in the ISTP Era,"* Guntersville, AL< September 15-20, 1997.
4. Ashour-Abdalla, M., J. Raeder, M. El-Alaoui, and V. Perroomian, Simulating Geotail magnetotail observations with magnetohydrodynamic and particle tracing, *Proceedings of the 1996 Chapman Conference on "The Earth's Magnetotail: New Perspectives,"* Kanazawa, Japan, November 5-9, 1996, submitted 1997.
5. El-Alaoui, M., M. Ashour-Abdalla, J. Raeder, V. Perroomian, L.A. Frank, W. R. Paterson, and J. M. Bosqued, Modeling magnetotail ion distribution through global magnetohydrodynamic and ion trajectory calculations, *Proceedings of the 1996 Huntsville Workshop on "Encounter Between Global Observations and Models in the ISTP Era,"* Guntersville, AL, September 15-20, 1996, submitted 1997.

E. Invited Presentations

1. Ashour-Abdalla, M., J. Raeder, J. Berchem, R. J. Walker, M. El-Alaoui, L. A. Frank, W. R. Paterson, S. Kokubun, T. Yamamoto, R. Lepping, and K. Ogilvie, 1996 Chapman Conference on "The Earth's Magnetotail: New Perspectives," Kanazawa, Japan, November 5-9, 1996.
2. Ashour-Abdalla, M., L. M. Zelenyi, J. Berchem, M. El-Alaoui, V. Perroomian, J. Raeder, R. L. Richard, D. Schriver, R. J. Walker, L. A. Frank, W. R. Paterson, K. Ackerson, S. Kokubun, T. Yamamoto, R. P. Lepping, and K. Ogilvie, Determination of particle sources for observed distribution functions, 1996 Huntsville Workshop on "Encounter Between Global Observations and Models in the ISTP Era," Guntersville, AL, September 15-20, 1996. (Abstract, pg. 25).